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ABSTRACT

In this study, the relationships between simple learning by accretion and various cognitive ability variables were explored. Computerized tests of five sources of individual differences were administered to a sample of 714 Air Force recruits, along with a trigram-English word paired-associate task, which was presented as a foreign language vocabulary learning task. Subjects were assigned at random to one of three groups: control, semantic elaboration, or interactive imagery. Subjects in the semantic elaboration group were instructed to generate sentences to link the trigram and the word in a memorable way. Subjects in the interactive imagery group were given the additional instruction of visualizing the generated sentence. Trigrams (CVCs) varied in meaningfulness across the two lists of eights pairs in the task. Results showed that meaningfulness and strategy had the expected main effects on learning and that strategy interacted with verbal knowledge in initial learning so that learners with more knowledge benefitted more than learners with less knowledge. Regression analyses showed that a representative measure from each proposed source made a significant unique contribution to the explained variance in paired-associate learning. Contains four figures and one table. (Contains 61 references.) (Author)

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ABSTRACT. In this study, the relationships between simple learning by accretion and various cognitive ability variables were explored. Computerized tests of five sources of individual differences were administered to a sample of 714 Air Force recruits, along with a trigram-English word paired-associate task, which was presented as a foreign language vocabulary learning task. Subjects were assigned at random to one of three groups: control, semantic elaboration, or interactive imagery. Subjects in the semantic elaboration group were instructed to generate sentences to link the trigram and word in a memorable way. Subjects in the interactive imagery group were given the additional instruction of visualizing the generated sentence. Trigrams (CVCs) varied in meaningfulness across the two lists of eight pairs in the task. Results showed that meaningfulness and strategy had the expected main effects on learning and that strategy interacted with verbal knowledge in initial learning so that learners with more knowledge benefitted more than learners with less knowledge. Regression analyses showed that a representative measure from each proposed source made a significant unique contribution to the explained variance in paired-associate learning.

AFTER A SERIES OF STUDIES conducted in the 1930s and 1940s, Woodrow (1946) concluded that there was little if any relationship between intelligence and the ability to learn. These conclusions went almost unchallenged until Allison (1960) and Stake (1961) reported extensive correlational studies in which a variety of learning tasks were related to a variety of psychometric measures of intelligence and achievement. Cronbach and Snow (1977) did an extensive review of the literature and concluded that cognitive abilities and the ability to learn were related, though only moderately. The same conclusions were drawn in more recent studies, (e.g., Hundal & Horn, 1977; Labouvie-Vief, Levin, Hurlbut, & Urberg, 1977).

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In the present study, I attempted to relate learning performance to cognitive abilities. More specifically, the purpose of this study was to determine if variables chosen to represent components of a general model of individual differences in knowledge and skill acquisition could account for individual variation in paired-associate learning, a relatively simple form of learning by accretion (Rumelhart & Norman, 1978). Learning by accretion denotes increases in knowledge obtained through the addition of propositions to existing knowledge structures or through the establishment of new connections between existing concepts. Paired-associate learning can be used effectively in vocabulary instruction and other curriculum areas requiring fact learning (for a review, see Pressley, Levin, & Delaney, 1982) and is an excellent predictor of school grades in English, science, math, and social studies (Stevenson, Hale, Klein, & Miller, 1968), and of end of course grades in Air Force foreign language learning (for a summary, see Carroll, 1962).

A Five-Source Theoretical Framework

A general theoretical framework for studies on individual differences in knowledge and skill acquisition was described by Kyllonen and Christal (1988) in their progress report on the Learning Abilities Measurement Program (LAMP). The framework described here differs only in the addition of a fifth source of individual differences, metacognition. Basically the framework proposes that individual variation in knowledge and skill acquisition is due to the operation of five sources: declarative knowledge, procedural knowledge or cognitive skill, working memory capacity, information processing speed, and metacognition

Declarative knowledge consists of the facts and concepts a person has stored in long-term memory. Bjorklund (1987) proposed three ways in which declarative knowledge can facilitate associative learning: (a) by making concepts in semantic memory more accessible; (b) by making the activation of semantic relations more automatic and less effortful; and (c) by facilitating

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the use of elaborative strategies. Rohwer (1980) had a similar proposal, referring to the semantic relations a person has stored as event repertoires. Learning is facilitated when the relations to be learned are similar to those already learned. Recent LAMP studies have found positive correlations between associative learning and knowledge as measured by verbal achievement and vocabulary tests (Kyllonen & Tirre, 1988; Kyllonen, Tirre, & Christal, 1989) thus providing indirect evidence in favor of the Bjorklund/Rohwer hypothesis.

Procedural knowledge refers to the "how-to" knowledge students have acquired (Anderson, 1983). Included in this category are cognitive skills, strategies, problem-solving heuristics, mnemonic techniques, and processing components acquired as part of the developmental process.

Several studies suggest that there is considerable variation in knowledge of effective learning strategies such as semantic elaboration and interactive imagery that accounts for a significant portion of the variance in overall associative learning success (Camp, Markley, & Kramer, 1983; Rohwer & Bean, 1973; Rohwer & Litrownik, 1983; Rohwer, Raines, Eoff, & Wagner, 1977; Wang, 1983). A recent study by Kyllonen, Tirre, and Christal (1989) demonstrated that training on an elaborative processing strategy interacted with verbal knowledge. The main finding was that everyone benefitted from training on how to construct memorable relations between word pairs, but subjects with more verbal knowledge benefitted more. This suggests that successful use of elaborative processing may depend on how much knowledge the student can bring to bear. The fact that all the subjects benefitted some suggests that strategic knowledge and verbal knowledge are uncorrelated; but this finding needs to be replicated.

Two semantic processing skills are hypothesized to play important roles in simple learning by accretion, both of which involve the activation or construction of relationships between items in semantic memory: semantic inference and incidental learning. Semantic inference is a major component of verbal analogy solution (Sternberg, 1977; Tirre, 1983; Whitely & Barnes, 1979). Nodes in semantic memory are presumed to be connected by semantic relations (e.g., Chaffin & Herrmann, 1984, 1987). Students gradually acquire knowledge of certain regular types of semantic relations, and this facilitates analogy solution (Tirre, 1983; Whitely & Dawis, 1974). Note the similarity to Rohwer (1980), who suggested that learning should become easier as students acquire more event repertoires (semantic relations). The hypothesis suggested here is that because relational construction is involved in both verbal analogy solution and elaborative processing in associative learning, verbal analogy solution should be a significant predictor of paired-associate learning.

The levels of processing framework of Craik and Lockhart (1972) suggested that a permanent memory trace could be established without conscious

effort so long as the stimuli were processed semantically (e.g., Craik & Tulving, 1975). It is worth considering whether students differ systematically in the ability to acquire information incidentally and whether this ability is predictive of intentional learning. In previous research (Tirre & Elliott, 1988), we demonstrated reliable individual differences in incidental memory for semantic relations and found significant correlations between this type of incidental memory and intentional learning from text. The same incidental memory task was used in the current study.

Working memory refers to a memory system dedicated to the temporary storage of information that arises during the performance of cognitive tasks such as reading, problem solving, and learning. Baddeley (1983) proposed that working memory consists of a limited-capacity central processor that directs the activities of several slave systems, including an articulatory loop that stores and manipulates speech-based information and a visuo-spatial scratch pad that generates and maintains visual images. Working memory has been shown to be important in complex accretive learning as in learning from text (e.g., Daneman & Green, 1986; Masson & Miller, 1983; Tirre & Pena, 1989), but data concerning its role in simpler types of accretive learning are scant. Recently, however, Baddeley, Papagno, and Valiar (1988) reported clinical evidence that the articulatory loop was involved in associative learning.

A second concept of working memory has been suggested by Anderson (1983) and by Card, Moran, and Newell (1986). In this concept, working memory is the subset of knowledge that can be accessed at a given moment—temporary knowledge structures receiving attention and permanent parts of long-term memory currently activated.

A study by Woltz (1988) explored the roles of the two concepts of working memory in skill acquisition. Subjects learned a rule-application task and took a variety of tests designed to assess the Baddeley (1983) concept of working memory and the Anderson (1983) concept of working memory as activation capacity. As predicted, tests of Baddeley's notion of working memory were predictive of initial declarative learning of rules and procedures, whereas measures of activation capacity were predictive of subsequent practiced performance of the skill.

Information processing speed refers to the rate at which a person can execute basic cognitive processes such as stimulus apprehension, encoding, comparison, decision, and long-term memory retrieval. A study by Kyllonen et al. (1989) sought to determine the role of processing speed in paired-associates learning. Kyllonen et al. hypothesized that students who could process information more quickly would have more time to construct relations between the stimulus and response terms and would consequently demonstrate better recall. Subjects were administered a paired-associates learning task in which several lists were presented at .5, 1, 2, 4, and 8 s per pair, as

well as a variety of cognitive tasks designed to assess processing latency. Results of the five experiments showed that memory search time consistently added to verbal knowledge in predicting learning when the study time was short (e.g., .5 and 1 s), but did not predict learning when study time was ample. Comparison time and simple reaction time also showed fair consistency in predicting learning, but the relationships were typically smaller.

Metacognition and executive processes are general cognitive skills acquired through experience (e.g., Brown & DeLoache, 1978). Baker and Brown (1984) describe two aspects of metacognition. The first is the student's concept of his abilities and their adaptability to demands of the learning situation. The second is self-regulation, which includes planning, monitoring, revising, and evaluating strategies for learning or problem solving. In this study the former was of interest because an earlier study (Tirre, 1984) had demonstrated a significant contribution of this variable to the prediction of verbal learning.

Reanalysis of Prior LAMP Research

A reanalysis of data collected in the LAMP laboratory for a different study (N = 855, Tirre, 1984) addressed several of the issues just discussed and subsequently motivated the present study. In the 1984 study, I sought to determine the factor structure underlying a diverse set of cognitive measures, which included various reasoning tests, 3 paired-associate learning tasks, the meaning-identity task, a learning-skills questionnaire, and the 10 measures of knowledge and cognitive skill contained in the Armed Services Vocational Aptitude Battery (ASVAB; Department of Defense, 1985).

The reanalysis focused on two questions. The first was whether reasoning skills and paired-associate learning would be correlated and whether inductive reasoning would be a stronger correlate than other forms of reasoning, with verbal analogies being the strongest of all because of the semantic feature extraction and comparison processes these two activities share. The second was whether reasoning skills, verbal knowledge, and strategic knowledge would make significant independent contributions to the explanation of paired-associate learning variance.

Reasoning skill was measured with computer-administered versions of several standard tasks used in the research literature: verbal analogies (Achenbach, 1970; Sternberg, 1977), linear syllogisms (Huttenlocher, 1968), grammatical reasoning (Baddeley, 1968; Baddeley & Hitch, 1974), letter series (Simon & Kotovsky, 1963), and number sets (Thurstone, 1938). The verbal analogy, letter series, and number-sets tests were selected to represent inductive reasoning.

The three paired-associate tasks were identical in procedure but different in content. The contents used in the tasks were CVC trigram pairs (a mixture

of high meaningfulness pairs and low meaningfulness pairs), picture pairs (real objects vs. random scribbles), and English word pairs (high vs. low imagery). For each task, 60 stimulus-response pairs were presented in 6 lists of 10 items each. Each pair was presented for 4 s. After the 10th pair of the list, a recognition test was given in which the stimulus was presented and the subject had to select the correct response term from among five alternatives. Distractors were other response terms presented in the current list. Half the subjects were given a 10-min lesson on semantic elaboration and visual imagery techniques that could be applied to the experimental learning tasks. The control subjects were left to their own devices.

The first step in the reanalysis was the computing of a composite or overall learning score as the average of the three learning tasks, as suggested by the measurement model proposed by Humphreys (1976). To test the hypothesis concerning reasoning skills, the correlations of the five reasoning tasks with the overall learning score (average of the three learning tasks) were compared after correcting for measurement error.[1] This reanalysis revealed identical rankings of correlations for the strategy-trained and control groups. Analogical reasoning had the highest correlation with associative learning (r = .499, .412, for strategy and control groups, respectively); followed by letter series (r = .457, .363, respectively), number sets (r = .413, .330), three term series (.375, .298), and grammatical reasoning (.367, .295). Thus, the three highest correlates of associative learning were inductive reasoning tasks, and the highest of these was analogical reasoning, as predicted.

The next analysis regressed the overall learning score on a set of cognitive ability scores representing verbal knowledge, verbal processing speed (meaning identity response time), general reasoning ability, quantitative reasoning (not included in general reasoning), technical knowledge, clerical speed and accuracy, and four subscale scores on elaborative strategies, deep semantic processing, methodical study habits, and self-assessment of learning abilities obtained from a learning skills questionnaire. In addition, a binary vector coding control versus strategy-trained subjects was included.

The regression analysis first created a full model consisting of all predictor variables, including all strategy by continuous variable product terms that coded the two-way interactions of interest. Removal of the two-way interactions did not result in a significant drop in the explained variance, so they were discarded. Removal of the control versus strategy-trained vector did result in a significant decrease, so it was retained in the equation. Further pruning of the equation was achieved with the backward elimination method. This resulted in a reduced model with four predictors accounting for 32.6% of the variance (adjusted, 32.3%). The predictors remaining in the equation were: general reasoning (sr = .347), strategy (sr = .324), self assessment of learning ability (sr = .109), and verbal knowledge (sr = .082), with each unique contribution significant at the .005 level (sr = semi-partial or part correlation).

The reanalysis of the Tirre (1984) dataset was important because it identified separate knowledge and ability factors that predict success in acquiring new associations and demonstrated the predicted relations between types of reasoning and paired-associate learning. Several questions remained unanswered, which the present study addressed. The first concerned semantic inference ability, a component of verbal inductive reasoning. To what extent would semantic inference ability help to explain associative learning, when working memory capacity is partialed out? Studies by Holzman, Pellegrino, and Glaser (1982, 1983) suggested a major role for working memory in inductive reasoning tasks, so it was necessary to evaluate the independent contributions of working memory and semantic inference in explaining learning.

A second question was whether working memory has a direct effect on associative learning, in addition to the suspected indirect effect through semantic inference. In other research, Kyllonen and Tirre (1988) found significant path coefficients from reasoning ability and verbal knowledge factors to general associative learning ability. The path from a memory span factor to associative learning was not significant. However, this is not sufficient evidence to rule out the involvement of working memory in associative learning. Memory span has been observed to not correlate with cognitive performance in situations where dual task measures of working memory do correlate substantially (e.g., Daneman & Carpenter, 1980).

The third set of questions concerns the role of strategic knowledge in associative learning. Past research in our laboratory (e.g., Kyllonen et al., 1989) found that all subjects benefitted from mnemonic strategy training but that subjects with a great deal of verbal knowledge benefitted more than those with little verbal knowledge. This finding suggests that verbal knowledge and strategic knowledge are independent of each other but that students with more verbal knowledge can take greater advantage of mnemonic strategies that involve accessing verbal knowledge. To our surprise, this knowledge-by-treatment interaction was not replicated in the Tirre (1984) dataset in any of the stimulus sets, including the word-pair set, which was nearly identical in format to the Kyllonen et al. materials.

With respect to strategic knowledge, the questions addressed in the present study are twofold: (a) whether strategy training interacts with verbal knowledge, verbal processing speed, semantic inference, working memory, or some other cognitive variable; and (b) whether an interactive imagery type of strategy is superior to a semantic elaboration type of strategy in which visual imagery is not explicitly prompted.

[1]Correction for attenuation was desirable because the reasoning tasks varied in reliability. The formula used was: $r_{corrected} = r_{observed}/R_{xx}$, where R_{xx} is the reliability of the predictor x.

The fourth set of questions concerns the role of verbal information processing speed in associative learning. Past LAMP research (Kyllonen et al., 1989) indicated that memory search speed was predictive of associative learning primarily when study time was severely limited. Other LAMP research (i.e., the Tirre, 1984, reanalysis) showed that verbal processing speed (including the memory search component) did not add to verbal knowledge, reasoning, and strategic knowledge in predicting associative learning under normal study conditions. The failure of verbal processing speed to predict learning under anything but speeded conditions could be due to choice of predictors. Thus, in the present study, a more diverse set of lexical and semantic processing speed tasks was considered.

In addition to these major questions, the present study investigated the degree to which intentional associative learning was predictable by incidental learning and if this incidental learning ability would add to skills demonstrated on other semantic processing tasks (verifying semantic relations and solving analogies) in predicting intentional learning by accretion. This study also investigated the degree to which metacognitive knowledge, as reflected in a learning strategies questionnaire, would predict learning.

Method

Subjects

The subjects were 813 Air Force basic recruits on their 6th day of basic training at Lackland Air Force Base, Texas. Three percent of these subjects were omitted from the study because they reported that English was a second language. Of the remaining 789 subjects, 714 had complete datasets determined by listwise deletion. Ages ranged from 17 to 27 years with a median age of 19. About 85% of the sample were high school graduates with no college. An additional 13% had some college but no degree. Approximately 20% of the sample were women.

Apparatus

The Air Force Human Resources Laboratory (AFHRL) Experimental Testing Facility is equipped with 30 Zenith 248 (IBM AT-compatible) computers placed in individual study carrels. The computers are equipped with enhanced graphics adaptor (EGA) color monitors and standard keyboards for response entry. All tests other than the Armed Services Vocational Aptitude Battery (ASVAB) were administered using a computer with the LAMP automated testing system software written in Turbo Pascal by OAO Corporation programmers under Air Force contract.

Criteria Tasks

The primary criterion task consisted of a CVC–English word paired-associate learning task with two lists of eight pairs. One list consisted of highly meaningful CVC trigrams (e.g., KUP, TIR, LIK) selected from Archer (1960) paired with English words of medium frequency and concreteness according to the Toronto word pool norms (Friendly, Franklin, Hoffman, & Rubin, 1982). The second list consisted of less meaningful CVC trigrams (e.g., KIJ, PUW, WEM) paired with English words selected by the same criteria. Both lists were administered to each subject, with half of the subjects receiving the highly meaningful list first. Two identically constructed versions of the learning task were administered to separate sets of subjects.

The learning task was presented as a foreign language learning task, in which the object was to learn the English meanings of Plutonian words as quickly as possible. The task began by presenting each pair on the CRT screen for 3.5 s. This was followed by test trials in which the CVC stimulus term would appear and the subject would be prompted to type in the first two letters of its English meaning. The shortened response format was used because a substantial proportion of Air Force recruits do not have typing skills. After the subject pressed the Enter key to register a response, the computer would display "Correct" or "Wrong," and give the correct answer, for example, "KUP means Loan" for 1 s. Pairs dropped out of the list after three successive correct responses.

Subjects were assigned to three groups at random. Control subjects were given no special instructions on how to approach the learning task. Subjects in the semantic elaboration group were instructed to create English words out of the CVC words and then create a simple sentence to connect the two words. Four examples were given to illustrate the process. Subjects in the interactive imagery group were instructed to proceed in a similar manner. That is, they were instructed to think of English words for the CVCs, generate a sentence depicting the interaction of the two objects named by the words, and then generate a mental image of this interaction. Four examples illustrated the process by describing the visual images that could be generated for each pair.

The second criterion task was a rapid presentation paired-associate task consisting of six 10-item lists of English word pairs. Each pair was given a single exposure for 1 s, which previous research had indicated was insufficient time for strategy use (Kyllonen et al., 1989). Following the 10th pair of each list, the subject was presented a recognition test in which the stimulus term of each pair was presented, and the subject had to select the correct response term from among five alternatives (each were response terms in the current list). The purpose of this second learning task was to provide a mea-

sure of associative learning under speeded processing conditions in order to replicate the Kyllonen et al. study.

Experimental Tests

In the Alphabet Recoding Working Memory Test (Woltz, 1988), subjects were presented with 36 series of three nonadjacent letters (e.g., H, R, W), each appearing on the center of the computer screen in succession for 1 s. After the final letter in the series, an integer ($-3 < i < 3$) was presented, which signaled the subject to move backward or forward by i to find a new string of letters. So if the string, H, R, W, were presented, followed by -3, the correct answer would be E, O, T. Solution time and accuracy were recorded.

This task was designed so that high-level verbal and quantitative skills would not be required for task performance. Although alphabet recall and counting processes were expected to be highly developed for this population, the possibility remained that performance on this task was to some degree dependent on these low-level skills.

Two features of this task were designed to maximize the demand for concurrent processing and temporary storage. First, the stimuli were presented with only a brief exposure; then they had to be maintained in memory. Second, subjects were not permitted to type in any new letter until all of the problem had been solved. Thus, partial solutions had to be maintained in memory along with unprocessed letters while counting forward or backward in the alphabet.

The Verbal Analogies Test (Sternberg & Nigro, 1980) was selected as a measure of semantic inference ability. It presented 60 items with four alternative answers. There were equal numbers of the following item formats:

A:B :: C: D1 D2 D3 D4,
A:B :: C1:D1 C2:D2 C3:D3 C4:D4,
A: B1 :: C1:D1 B2 :: C2:D2 B3 :: C3:D3 B4 :: C4:D4

where A, B, C, and D were common English words. The subject typed in the number (1 to 4) corresponding to his answer. The computer gave accuracy and response-time feedback on correct responses and no feedback on incorrect responses.

The Basic Analogical Reasoning Test with Cued Recall was based on a verbal analogies test designed by Achenbach (1970) to identify students who relied on verbal association rather than reasoning to solve analogy problems. In this test, subjects were presented 68 standard analogy problems with five alternatives. Half of the items were written so that one distractor was a strong associate of the third term of the analogy (e.g., pig is to boar as dog is to: cat, smoke, ant, turtle, wolf). In this case, cat is a strong associate of dog, but

does not correctly complete the analogy, the right answer being wolf. The other half of the items were written so that none of the distractors were strong associates of the third term of the analogy (e.g., keep is to retain as have is to: pain, lot, power, recess, possess).

In the present version of the task, items were presented individually on the computer screen. There were two frames per item. The analogy domain (A is to B) was presented on the first frame and the remainder of the item (C is to D1, D2, D3, D4, D5) was presented on the second frame, so that encoding time for the domain could be estimated separately. After the 17th item, subjects were given a surprise cued-recall test. The A term of the analogy was presented (e.g., keep) along with five possible alternatives for B (e.g., retain). The alternatives consisted of the first and last letters of B terms separated by two blanks (e.g., R__N). The distractors were other previously encountered B terms. Subjects typed the number corresponding to their choice. After the cued-recall test, subjects were told that there would be no further surprise recall tests, and the analogy test was resumed.

The Semantic Relations Verification Test with Incidental Cued Recall presented subjects with simple sentences such as "Plumbers work with pipes" to verify as *true* or *false*. Items were arranged in three blocks of 48, with approximately four sentences (half true) for each of 12 semantic relations represented in each block. The semantic relations were selected from those identified by Chaffin and Herrmann (1984, 1987). The following are examples of four relations used: synonymity (buy–purchase), agent-action (artist–paints), invited attributes (hospital–clean), and functional part-whole (engine–car).

The first and last words of each statement were presented in green uppercase letters; whereas the middle words were presented in white lowercase letters. This served to make the end words more visually prominent. After the first block of 48 items, subjects were presented a surprise cued-recall test. The subject was presented either the first word for a statement preceding a blank, or the last word following a blank. The subject was required to type in the first two letters of the word's complement. If the subject were presented "PLUMBERS–__?__," Pl was the correct answer. The second block of 48 items was identical to the first with the exception that subjects were told that a cued-recall test would follow. A time limit of 5 s was set on individual verification items to prevent excessive study time, though this may have been unnecessary because subjects were still under time pressure. The third block of verification items followed the second cued-recall test. This was not followed by a recall test.

The Phonological Processing Speed Test was patterned after a test devised by Olson, Kliegl, Davidson, and Foltz (1985) to measure lexical access by speech recoding. Subjects were presented 68 pairs of nonword letter strings, one of which sounded like a real word (e.g., baik–bape). The task

was to select the string that sounded like a real word. Subjects were instructed to respond as quickly as they could without sacrificing accuracy and were given response time feedback on correct responses only.

The Orthographic Processing Speed Test also originated with Olson et al. (1985). This test was designed to measure direct access time to the lexicon. Subjects were presented 48 pairs of letter strings, each pair consisting of strings identical in pronunciation (e.g., smoak–smoke). The subject's task was to select the string that spelled a real word.

The Meaning Identity with Repeated Items Test was patterned after one devised by Woltz (1988) to measure speed of semantic comparison on nonrepeated trials and activation capacity as response latency savings on repeated trials and consisted of 220 trials in which the subject had to decide whether two words had the same or different meanings. The test began with 40 fairly difficult matching trials (e.g., exonerate–vindicate) intended to measure vocabulary knowledge. Two words were presented on the center of the computer screen with one word above the other, skipping a line. Following these 40 trials, 180 trials were presented in which the words were known to 90% of the Air Force recruit population (e.g., infant–baby). Half of these trials were repeats of earlier trials. Trials were repeated after lags of 1, 2, 4, and 8. Half of the repeated trials were presented as exact replicas of the original trials, and half were presented so that the correct response (same or different) was the opposite of the original correct response. In the latter type of repeated trial, the top word remained the same but the bottom word was different. The instructional set and feedback were the same as for the previous two tests.

The Learning Strategies Questionnaire (LSQ) was based on a self-report instrument developed by Schmeck (Schmeck, 1983; Schmeck, Ribich, & Ramanaiah, 1977). It consisted of 71 statements to which the subjects responded *agree* or *disagree*. Statements corresponded to four scales: (a) Deep Processing, or the extent to which the subjects critically evaluated, conceptually organized, and compared and contrasted the information they studied; (b) Elaborative Processing, or the extent to which subjects translated information encountered in texts into their own wording, generated personal concrete examples, and used visual imagery to encode new ideas; (c) Self Assessment of Memorization Ability, or the proficiency with which subjects retained specific, detailed information, such as names, dates, places; and (d) Methodical Study, or the extent to which the subject engaged in systematic study practices, such as rewriting notes, outlining text, generating questions, or drilling.

ASVAB Subtests

Three tests were selected from the ASVAB as indicators of verbal knowledge and two tests were selected as indicators of reasoning skill. The ASVAB is the vocational aptitude battery used for enlisted personnel selection and classification purposes in the United States armed services (Department of Defense, 1985).[2] Five of the subtests comprising the ASVAB were used as predictors in this study: General Science, Word Knowledge, Paragraph Comprehension, Arithmetic Reasoning, and Mechanical Comprehension.

The General Science subtest (Verbal Knowledge Factor, 25 items, 11 min) is composed of multiple-choice items assessing knowledge of life science, physical science, and earth science. The Word Knowledge subtest (Verbal Knowledge Factor, 35 items, 11 min) measures vocabulary with two types of items. About 60% of the items take the form "______ most nearly means. . . ." The other 40% present the target word in complete sentences and require the examinee to select the word which could be used in place of it.

According to the manual, the Paragraph Comprehension subtest (Verbal Knowledge Factor, 15 items, 13 min) was designed to measure reading comprehension skill. Fifteen passages are presented, varying in size from 30 to 120 words. Each is followed by one multiple-choice question.[3] The Arithmetic Reasoning subtest (Quantitative Reasoning Factor, 30 items, 36 min) consists of algebra word problems designed to emphasize the mathematical operations required for solution rather than computational complexity. This test was selected as an indicator of reasoning ability other than analogical reasoning. Larson, Merritt, and Williams (1988) reported a correlation of .53 with Ravens Progressive Matrices scores obtained on a sample of U.S. Navy enlisted personnel.

Items in the Mechanical Comprehension subtest (Technical Knowledge and Skill Factor, 25 items, 19 min) measure skill in inducing and applying mechanical principles in the context of problems involving simple devices. Most items present pictorial or graphic displays. This test was also selected as an indicator of reasoning ability. Larson et al. (1988) reported a correlation of .60 with Ravens Progressive Matrices scores.

Procedure

All testing was conducted at the Air Force Human Resources Laboratory (AFHRL) Experimental Testing Facility at Lackland Air Force Base, Texas.

[2]Descriptive information on the ASVAB was obtained from the Technical Supplement to the Counselor's Manual for the Armed Services Vocational Aptitude Battery, published by the Department of Defense. Factor analyses of the ASVAB were reported by Ree, Mullins, Mathews, and Massey (1982).

[3]The ASVAB Counselor's Manual claims that the contents of the passages were selected so as to minimize the effects of the examinee's prior knowledge in answering the questions. Examination of test items suggests that the selection strategy might have been to choose all highly familiar topics which might be found in popular magazines. This strategy may have had the opposite effect of inducing examinees to rely on prior knowledge.

Subjects were seated at the carrels and began the session by reading a short briefing on the purpose of the study. This was followed by a set of exercises designed to familiarize them with the keyboard.

The criterion tasks were the first tests to be administered, with the rapid-presentation English word paired-associate task being the first test. Following this test, the subjects were given the CVC–English word paired-associate task. Prior to actual testing on the CVC–English word task, subjects were given either instruction on appropriate mnemonic strategies (semantic elaboration and interactive imagery groups) or no special instruction (control group). The learning strategies questionnaire was fixed last in the battery. All of the remaining tests were presented in different random orders to each subject. A 5-min break was given at the approximate midpoint of the 3-hr session. The ASVAB had been administered at various times prior to enlistment in the Air Force.

Results

Predictor and Criterion Test Scores

Means, standard deviations, and reliability estimates for the experimental test scores and ASVAB subtest scores are found in Table 1. The Alphabet Recoding Working Memory Test (AWM; Woltz, 1988) was scored for accuracy at each combination of direction (+ or −) and level (1, 2, and 3). A single overall accuracy score (AWMPC, overall percent correct) was used in the regression analyses along with a mean solution time (AWMST) score. Reliability estimated by the odd–even method was .791 for AWMPC. The Sternberg/Nigro Verbal Analogies Test (VAT; Sternberg & Nigro, 1980) was scored for accuracy (VATPC) and for median response time (VATRT). Reliability was estimated at .827 for VATPC and .934 for VATRT.

The Basic Analogies Test with Incidental Cued Recall (BART: Achenbach, 1970) was scored for reasoning accuracy and response time (BARTPC and BARTRT) and these correlated substantially with the same from the Sternberg/Nigro VAT (r = .57 for accuracy, and .50 for response time, respectively). BARTPC and BARTRT were not used in the subsequent regression analyses to avoid experimental dependency with the incidental recall score from the same test. The incidental recall score (BARIR) consisted of the percent of analogy domain B terms that were correctly recalled given the A term as a cue. The BARIR score had only modest reliability (R_{xx}' = .619), mostly because of its small size (17 items).

The Semantic Relations Verification with Incidental Cued Recall (SRV; Chaffin & Herrmann, 1984, 1987) was scored for median verification time on correct responses (SRVRT, R_{xx}' = .985) and accuracy (SRVPC, R_{xx}' = .799). The second block of 48 items assessed incidental recall of A given B

TABLE 1
Descriptive Statistics and Reliability Estimates

Test	*M*	*SD*	*Rxx'*
Alphabet Recoding Solution Time (AWMST)	9.58	6.02	na
Verbal Analogies Solution Time (VATRT)	7.66	2.05	.934
Orthographic Processing Speed (ORPRT)	.88	.16	.966
Phonological Processing Speed (PHPRT)	1.95	.57	.963
Meaning Identity Easy Items RT (MIDRT)	1.26	.33	.960
Meaning Identity Residual Activation (RESACTV)	0.00	.08	.300
Semantic Relations Verification Speed (SMRRT)	1.83	.37	.985
Alphabet Recording (AWMPC)	30.9	15.6	.791
Verbal Analogies (VATPC)	67.2	13.4	.827
Orthographic Processing Accuracy (ORPPC)	97.0	3.1	.834
Phonological Processing Accuracy (PHPPC)	86.4	11.1	.904
Meaning Identity Difficult Items (MIDPC)	76.0	12.4	.686
Meaning Identity Easy Items PC (MIDEPC)	93.9	4.0	.685
Semantic Relations Verification Accuracy (SMRPC)	91.9	4.5	.799
Incidental Recall (SMRIRPC)	44.6	13.7	.828
Incidental Recall of Analogy Terms (BARIRPC)	71.2	16.3	.619
LSQ Deep Processing (LSQDPPC)	66.6	18.1	.896
LSQ Self-Assessment of Memory (LSQSAPC)	69.3	20.8	.915
ASVAB General Science	19.4	3.3	.598
ASVAB Word Knowledge	29.6	4.1	.683
ASVAB Paragraph Comprehension	12.9	1.8	.572
ASVAB Arithmetic Reasoning	23.2	4.6	.831
ASVAB Mechanical Comprehension	17.7	3.8	.752
Rapid Presentation Paired Associates (RPPAPC)	53.8	15.5	.871
Trigram–Words Trials to Criterion (TWPATTC)			
All cases	78.2	41.0	.557
Control	83.7	38.2	
Interactive Imagery	73.2	38.9	
Semantic Elaboration	78.1	44.9	
Trigram–Words % Correct Recall (TWPAPC)			
All Cases	50.6	13.4	.608
Control	47.8	11.7	
Interactive Imagery	52.4	14.0	
Semantic Elaboration	51.5	14.0	
Trigram–Words 1st 8 Trials (TWPAF8PC)			
All Cases	19.7	14.9	.568
Control	17.5	12.6	
Interactive Imagery	21.4	16.1	
Semantic Elaboration	19.9	15.4	

Note. RT signifies median response time, PC signifies percent correct. Reliability was estimated as the corrected split half correlation for the computerized predictors. Reliability for ASVAB tests was computed as the stability coefficient multiplied by the internal consistency (alpha). Reliabilities for the trigram–words test scores were estimated as proportion of total variance due to individual differences.

or B given A; and this was scored as percent correct recall (SRVIR, R_{xx}' = .828). SRVIR correlated .33 with BARIR. This correlation is .47 when corrected for measurement error in both variables.

The Phonological and Orthographic Processing Speed Tests (PHPS; ORPS; Olson et al., 1985) were scored for both median response time on correct answered items (R_{xx}' = .963, .966, respectively) and accuracy (R_{xx}' = .904, .834, respectively). The Meaning Identity with Repeated Items Test (MID; Woltz, 1988) was scored for three parameters. A vocabulary score was obtained from the first 40 items (MIDPC, R_{xx}' = .686). A median response time on correctly answered easy items (error rate < .10) was obtained to indicate semantic retrieval and comparison time (MIDRT, R_{xx}' = .985). The third parameter was response time on second occurrences of items residualized on response time on nonrepeated items (RESACTV). This parameter was intended to measure activation capacity, but proved to have low reliability (R_{xx}' = .300).

The Learning Strategies Questionnaire (LSQ; Schmeck, 1983; Schmeck et al., 1977) was scored for four subscales: self-assessment of learning abilities (LSQSA), propensity to engage in deep processing (LSQDP), propensity to engage in elaborative processing (LSQEP), and methodical study habits (LSQMS). In contrast to our prior study (Tirre, 1984) summarized earlier, there was no variance on propensity to engage in elaborative processing—all respondents reported using these strategies. In addition, the correlation between methodical study habits and learning was essentially zero. As a consequence, only the LSQDP and LSQSA scales were retained for further analysis.

The Trigram–Word Paired Associate Learning Task (TWPAL) yielded three criterion scores: trials to criterion (TWPATTC), percent correct on first eight trials (TWPAF8PC), and percent correct on all trials (TWPAPC). The correlation between TWPAPC and log TWPATTC was −.92. The reliability of this learning task cannot be estimated with the conventional psychometric formulas because the assumptions of such procedures are violated. The best way to estimate the reliability of such a task would be to correlate parallel forms of the task. Although we have parallel forms, they were not administered to the same subjects. A second way to estimate the reliability would be to determine how much of the overall variance (between and within subjects) was due to individual differences (see Cohen & Cohen, 1975). Using this procedure, reliability was estimated at .608 and .568, for TWPAPC and TWPAF8PC, respectively.

The Rapid Presentation Paired Associates Test (RPPA) yielded one score of interest: overall percent correct recognition (RPPAPC) on the cued recognition tests following each list presentation. Recognition latency was also recorded, but was not analyzed. Reliability was estimated to be .871 for the percent correct recognition score.

Creation of Composite Variables

To reduce the number of predictor variables, composite variables were created, consisting of unit weighted averages of conceptually related variables. A verbal knowledge score (VKN), for instance, was computed as the average of standardized scores on the ASVAB Word Knowledge, General Science, Paragraph Comprehension subtests, and the Meaning Identity vocabulary test. Lexical/semantic processing speed (LSRT) was computed as the average of standardized response time scores on the following tests: ORPS, PHPS, SRVT, and MID (excluding the second presentation of items). A complementary accuracy score (LSACC) was computed as the average of the percent correct scores on the same tests (though the difficult items on the MID were excluded and used instead as a vocabulary measure as described earlier). The fourth composite variable was the average of the two incidental learning scores, BARIR and SRVIR.

Correlations Between Predictor and Criterion Variables

It is instructive to examine the simple correlations found between the cognitive ability measures and learning criteria before considering the details of the multiple regression analyses. Correlations were corrected for measurement error in the predictor to permit more valid comparisons. Table 2 shows the correlations for the whole task criteria, TWPATTC and TWPAPC. The best

TABLE 2
Correlations Between Cognitive Predictors and Learning Task Criteria

	Criteria							
	TWPATTC		TWPAPC		TWPAF8PC		RPPAPC	
Predictor	r_c	r_o	r_c	r_o	r_c	r_o	r_c	r_o
INCLRN	−.546	−.483	.570	.503	.502	.443	.458	.409
VATPC	−.501	−.453	.485	.441	.396	.360	.392	.361
VKN	−.409	−.378	.448	.414	.380	.351	.374	.346
AWMPC	−.432	−.388	.443	.394	.352	.313	.298	.267
ARITHRES	−.385	−.325	.404	.336	.363	.302	.365	.300
LSACC	−.399	−.379	.402	.386	.311	.298	.316	.309
MECHCOMP	−.268	−.201	.299	.225	.275	.207	.227	.163
LSQDP	−.260	−.246	.254	.240	.192	.182	.235	.222
LSQSA	−.167	−.162	.191	183	.171	.164	.193	.185
LSRT	.137	.135	−.185	−.184	−.178	−.177	−.240	−.239

Note. r_c denotes correlations that have been corrected for measurement error; r_o denotes observed correlations. Variables involving ASVAB subtests have been corrected for both stability and internal consistency. N = 714.

predictor of meaningful paired-associate learning was incidental learning (INCLRN, r = .570 for TWPAPC, −.546 for TWPATTC collapsing over list-group combinations). It is not surprising that incidental learning would be highly predictive of intentional learning, but it is interesting to note that these two forms of learning are far from identical, having about 30% of the variance in common.

The second highest correlate of paired-associate learning was semantic inference as measured by verbal analogies (VATPC, r = .485 for TWPAPC, −.501 for TWPATTC). The correlations for verbal analogies were higher than those obtained for the other reasoning skills, such as arithmetic reasoning (ARITHRES, r = .404, −.385) and mechanical reasoning (MECHCOMP, r = .299, −.268), thus replicating the reanalysis of the Tirre (1984) dataset.

The next three sets of correlations were essentially equal to those obtained with the arithmetic reasoning test. That is, the average absolute correlations obtained with lexical/semantic processing accuracy (LSACC), working memory (AWMPC), and verbal knowledge (VKN) ranged from .400 to .438. Finally, the lowest significant correlations were found with a self-reported tendency to employ deep processing (LSQDP, r = .254, −.260), a self-assessment of learning ability (LSQSA, r = .191, −.167), and with lexical-semantic processing speed (LSRT, r = −.185, .137).

A similar pattern of correlations was found with the rapid presentation paired-associates test (RPPA). The highest correlations were found with incidental learning (INCLRN, r = .458) and with verbal analogies (VATPC, r = .392). This was followed by verbal knowledge (VKN, r = .374), arithmetic reasoning (r = .365), and accuracy on the lexical-semantic processing tasks (LSACC, r = .316).

There were two notable differences in the pattern of correlations found for RPPA. The first is that working memory correlated substantially less well with learning (AWM, r = .298 for RPPAPC, r = .443 for TWPAPC). This difference is significant, $t(712) = 3.94$, $p < .001$ (computed on raw correlations). The second is that lexical-semantic processing speed correlated somewhat better (LSRT, r = −.240 for RPPAPC, r = −.185 for TWPAPC, r = .137 for TWPATTC). This difference was significant only for the RPPAPC–TWPATTC comparison, $t(712) = -5.96$, $p < .001$. The latter finding is consistent with the hypothesized role of information processing speed in rapidly presented paired-associates learning.

Main Regression Analyses for the Trigram–Word Task

Zero-order correlations are the best available data for the substantive interpretation of relationships between the predictor and criterion variables. However, to test hypotheses concerning the relationship of one cognitive ability variable

to learning, while controlling one or more other variables, part correlation, regression, or related procedures must be employed.

A combination of simultaneous and hierarchical inclusion regression modeling procedures (Cohen & Cohen, 1975) were used to analyze the individual differences variance. The square semi-partial or part correlations (sr) resulting from a simultaneous inclusion regression analysis reflect the amount of criterion variance that each predictor uniquely explains. When the domain of potential predictors has been extensively sampled, as in the present study, a significant unique contribution strongly suggests that the predictor should be included in the model of the phenomenon being studied.

The regression equation was constructed in two steps. On Step 1, a binary vector coding the two versions of the trigram-word paired-associates task, two binary vectors coding the three strategy groups (control, semantic elaboration, interactive imagery), and all the cognitive ability predictors were entered into the equation. On Step 2, the SPSS forward-inclusion method was used to allow the individual product terms carrying the strategy group by ability interactions to enter if their contribution to the explained variance was significant at the .05 level.[4] The same analysis was applied to all three criteria from the trigram-word paired-associates task, that is, log transformed trials to criterion (TWPATTC), percent correct over all trials (TWPAPC), and percent correct on first eight trials (TWPAF8PC). Analysis of TWPAF8PC enabled determination if any predictor was particularly strong for the initial encoding of the trigram–word pairs.

TWPATTC and TWPAPC are simply alternative measures of overall learning. For simplicity, the results for TWPAPC (Table 3) are summarized here and then discrepant findings for TWPATTC are noted. As the regression summary (Table 3) shows, there were several predictors significant at the .001 level. Among these were incidental learning (INCLRN, sr = .255), working memory (AWMPC, sr = .140), interactive imagery instructions (G1, sr = .109), and semantic elaboration instructions (G2, sr = .106). Verbal analogy solution (VATPC, sr = .082) and verbal knowledge (VKN, sr = .078) were significant at the .01 level; and lexical-semantic processing accuracy (LSACC, sr = .074) was significant at the .02 level. The results for TWPATTC are highly similar with the exception that the unique contribution for verbal knowledge was marginally significant ($p < .051$) and the unique contribution for LSRT was significant ($sr = -.086$, $p < .005$). The sign of the regression coefficient for LSRT indicates that this variable was operating as a suppressor in the regression equation.

The regression model of TWPAF8PC differs in only one important detail (see Table 3). Verbal knowledge interacted with strategy instruction in such a

[4]Because of the large sample size and number of predictors, only contributions that meet or exceed the .01 level of significance will be discussed in detail.

TABLE 3
Regression Summaries for Four Paired-Associate Learning Criteria

Variable	TWPAPC β	TWPAPC t	TWPATTC β	TWPATTC t	TWPAF8PC β	TWPAF8PC t	RPPAPC β	RPPAPC t
VERSION	-084	-2.87**	079	2.64**	-119	-3.74***	na	na
VKN	107	2.68**	-079	1.96*	-057	-.91	068	1.52
AWMST	022	.66	-024	-.72	-003	-.08	-009	-.24
AWMPC	174	4.80***	-174	-4.69***	131	3.32***	050	1.22
LSRT	068	1.92	-105	-2.89**	036	.94	-057	-1.44
LSACC	093	2.55*	-100	-2.69**	059	1.50	063	1.55
MECHCOMP	036	1.06	-015	-.44	052	1.43	016	.42
ARITHRES	026	.73	-017	-.47	041	1.04	085	2.12*
VATRT	-065	-1.89	038	1.10	-093	-2.52*	-054	-1.42
VATPC	113	2.82**	-150	-3.70***	090	2.08*	102	2.28*
INCLRN	306	8.76***	-284	-7.98***	290	7.69***	242	6.19***
LSQSA	070	1.82	-026	-.67	085	2.05*	081	1.90
LSQDP	050	1.26	-102	-2.52*	008	.19	041	.92
RESACTV	-005	-.15	013	.44	012	.38	031	.94
G1 (INT IMAG)	128	3.73***	-120	-3.43***	65	1.75	na	na
G2 (SEM ELAB)	126	3.66***	-103	-2.94**	033	.89	na	na
G1 X VKN	na	na	na	na	090	2.01*	na	na
G2 X VKN	na	na	na	na	149	3.35***	na	na
Final statistics								
R/adjusted *R*	.640/.630		.622/.611		.560/.544		.509/.495	
F (k, 714-k-1)	30.30***		27.55***		17.61***		18.81***	

Note. Decimals have been omitted from beta coefficients. na indicates that a variable was not applicable (not used) in a given equation. Degrees of freedom can be computed using k as the number of predictors in equation.

*$p < .05$. **$p < .01$. ***$p < .001$.

way that students with greater knowledge were more likely to benefit from strategy instructions (especially instructions to use semantic elaboration) than students with less knowledge. This replicates the Kyllonen et al. (1989) finding.

Rapid Presentation Paired Associates

Finally, consider the analysis of the rapid presentation word paired-associates task (RPPAPC, see Table 3). Incidental learning was the only predictor that met the .01 level of significance (sr = .206); though two reasoning skill variables were significant at the .05 level (VATPC, sr = .074, and ARITHRES, sr = .067). These findings suggest that when a student intends to learn but task demands prevent effective strategic behavior, learning is largely a function of his or her incidental learning proficiency and perhaps facility at reasoning.

Analyses Concerning Role of Incidental Learning

These analyses indicated that incidental learning proficiency was the best predictor of meaningful associative learning. Verbal analogies, verbal knowledge, knowledge of mnemonic strategies, and working memory each contributed significantly to the prediction equation, but their contributions were relatively meager in comparison. A second set of questions was suggested by these findings. First, what would the regression equation be like without incidental learning? Second, what combination of variables predicts incidental learning and how does this equation differ from that found for intentional learning?

When incidental learning is excluded from the predictor set, the regression coefficients (and semipartial correlations) for verbal knowledge and verbal analogies show an appreciable increase in the prediction of TWPATTC and TWPAPC (see Table 4). The best predictor of learning was verbal analogy performance (VATPC, sr = −.183 for TWPATTC, sr = .160 for TWPAPC, $p < .001$), followed by working memory (AWMPC, sr = −.143, .143, $p < .001$). The contributions of the strategy variables were essentially unchanged from the previous analysis. These were followed by verbal knowledge (sr = −.096, .119, $p < .002$), and by LSACC (sr = −.090, .084, $p < .006$).

These results suggest that verbal knowledge and verbal analogies would be the best predictors of incidental learning, and these predictions were supported by the regression analysis of incidental learning (see Table 4). There were only four significant predictors of incidental learning. Verbal analogy solution was the best predictor (sr = .244, $p < .001$), followed by verbal knowledge (sr = .133, $p < .001$). A second reasoning skill variable, arith-

TABLE 4
Regression Analyses of INCLRN and of Paired-Associate Learning Excluding INCLRN as a Predictor

Predictor	TWPAPC β	TWPAPC t	TWPATTC β	TWPATTC t	INCLRN β	INCLRN t
VERSION	−089	−2.90**	084	2.68**	na	na
VKN	162	3.90***	−130	−3.11**	179	4.21***
AWMST	041	1.17	−042	−1.19	062	1.71
AWMPC	179	4.68***	−178	−4.61***	014	.37
LSRT	054	1.45	−091	−2.42*	−047	−1.22
LSACC	106	2.76**	−112	−2.89**	042	1.07
MECHCOMP	045	1.30	−025	−.69	032	.87
ARITHRES	058	1.54	−047	−1.23	104	2.68***
VATRT	−068	−1.89	041	1.14	−010	−.27
VATPC	210	5.21***	−241	−5.91***	320	7.75***
LSQSA	072	1.79	−029	−.70	010	.23
LSQDP	034	.81	−087	−2.06*	−054	−1.27
RESACTV	−025	−.79	032	1.02	−066	−2.07*
G1 (INT IMAG)	130	3.61***	−122	−3.34***	na	na
G2 (SEM ELAB)	126	3.48***	−103	−2.82**	na	na
G1 X VKN	na	na	na	na	na	na
G2 X VKN	na	na	na	na	na	na
Final statistics						
R/adjusted R	.588/.575		.576/.563		.554/.543	
F (k, 714-k-1)	24.54***		23.06***		25.81***	

Note. Decimals have been omitted from beta coefficients. na indicates that a variable was not applicable (not used) in a given equation. Degrees of freedom can be computed using k as the number of predictors in equation.

*$p < .05$ **$p < .01$ ***$p < .001$.

metic reasoning, chipped in significantly ($sr = .084$, $p < .01$) as well. A small contribution was made by residual activation ($sr = -.065$, $p < .05$). Conspicuous in its absence was working memory, whose semipartial correlation was not significant ($p > .50$). These results are consistent with the hypothesis that incidental learning is largely a function of existing knowledge and the ability to induce relationships between concepts. The attentional capacity variety of working memory does not appear to play a major role in the incidental acquisition of new associations, though activation capacity may do so.

Analysis of Experimental Variables

For each of the three dependent variables, interactive imagery instructions resulted in slightly better learning performance than did semantic elaboration

(see Table 1). However, follow-up t tests indicated that these differences were not significant for the two full-task criteria ($t = 1.25$ for TWPATTC, $t = -.79$ for TWPAPC, $df = 726$). The semantic elaboration versus interactive imagery contrast was significant only for TWPAF8PC ($t = 2.21$, $p < .03$), indicating a small but reliable advantage for interactive imagery in the initial encoding of trigram–word pairs.

There was one within-subjects treatment variable, namely, the meaningfulness of the trigram stimuli. As expected, meaningful stimuli were easier to learn, $F(1, 695) = 359.72$, $sr = .360$, $p < .001$ for TWPAPC, $F(1, 695) = 324.84$, $sr = -.368$, $p < .001$ for TWPATTC. Meaningfulness did not interact with learning materials, strategy training, or with any cognitive ability for overall learning as measured by the two main dependent measures. The results for TWPAF8PC were essentially the same; only a main effect of meaningfulness was found, $F(1, 695) = 179.87$, $sr = .307$, $p < .001$.

Path Models

To represent and test the system of relationships examined here, a path analysis was performed using the EQS structural equations program (Bentler, 1985). Recall accuracy on trigram-word paired-associate task was selected as the ultimate dependent variable. The experimental variables were excluded from this analysis leaving only the individual differences variables.[5] Of the individual differences variables, only those which had demonstrated significant unique contributions to the regression equations were retained for further study. One additional deletion was arithmetic reasoning (ARITHRES). Arithmetic reasoning was excluded from this analysis because no causal role had been hypothesized for this variable in the previous regression modeling. Arithmetic reasoning and mechanical comprehension had been included in the previous analyses to provide evidence that something unique to verbal analogy solution was predictive of accretive learning and not simply a generic reasoning ability.

Causal modeling requires the analyst to specify causal hypotheses a priori in terms of structural equations. The process begins by deciding which variables are dependent (endogenous) and which are independent (exogenous). Initially, three variables were considered as independent variables in the Bentler (1985) sense: verbal knowledge (VKN), working memory capacity (AWMPC), and residual activation (RESACTV). Independent variables are assumed to covary without causal relationship. This left verbal analogy

[5]G1 and G2, the binary vectors coding strategy treatment group can be excluded from this analysis because they were uncorrelated with the individual differences variables. The only effect of their exclusion is a somewhat smaller multiple R for the criterion.

solution and LSACC as dependent variables for which hypotheses had to be generated. In this particular case, some hypotheses were available as the result of the regression models reported earlier for TWPAPC and INCLRN.

Hypotheses were available for verbal analogy solution from research conducted by Tirre (1983). According to the theory developed in this earlier work, verbal analogy solution requires knowledge of word meanings (VKN), carefulness in processing semantic information (LSACC), and sufficient working memory (AWMPC) to execute the processing steps while maintaining activation of semantic information and intermediate products of the solution process.

Hypotheses were somewhat more difficult to specify for LSACC. Errors may result because of lapses in attention. Thus, students with less attentional (or working memory) capacity might be expected to make more errors. Another possibility is that students with very low levels of verbal knowledge (VKN) make more errors because they do not recognize certain words appearing in test trials. These hypotheses comprise Model A, represented in Figure 1.

Three additional models might be proposed. Path Model B (see Figure 2) is the same as path Model A except that LSACC is hypothesized as a determinant of VKN. This hypothesis states that people who carefully process lexical and semantic information acquire more verbal knowledge than those who process such information less carefully. The third path model (C, see Figure 3), is an elaboration of Model B that hypothesizes a causal role for working memory (AWMPC) in addition to LSACC in determining how much verbal knowledge people acquire. The fourth and final model (D, Figure 4) assumes that LSACC is not determined by any variable in the system but covaries with verbal knowledge, working memory, and residual activation.

The results of the analyses corresponding to Models A, B, C, and D are presented in Figures 1, 2, 3, and 4, respectively. As it turns out, two of the models provided a good degree of fit to the data, and two models can be rejected because of significant residual correlations. Models B and C both resulted in significant chi-squared values (χ^2 = 29.9, p = .001; χ^2 = 14.85, p = .0379, respectively) and so may be rejected. In contrast, Models A and D both resulted in nonsignificant chi-squared values (χ^2 = 6.11, p = .295; χ^2 = 5.96, p = .2021, respectively). The other goodness-of-fit indices are highly comparable as well, leaving no statistical basis for choosing between Models A and D. Since the only way in which these models differ is in their treatment of LSACC, there is the consolation that the causal relationships shared by the two models are consistent with the data.

Discussion

As a whole, the results of this study suggest that a substantial amount (approximately 68%) of the systematic variance in paired-associates learning can

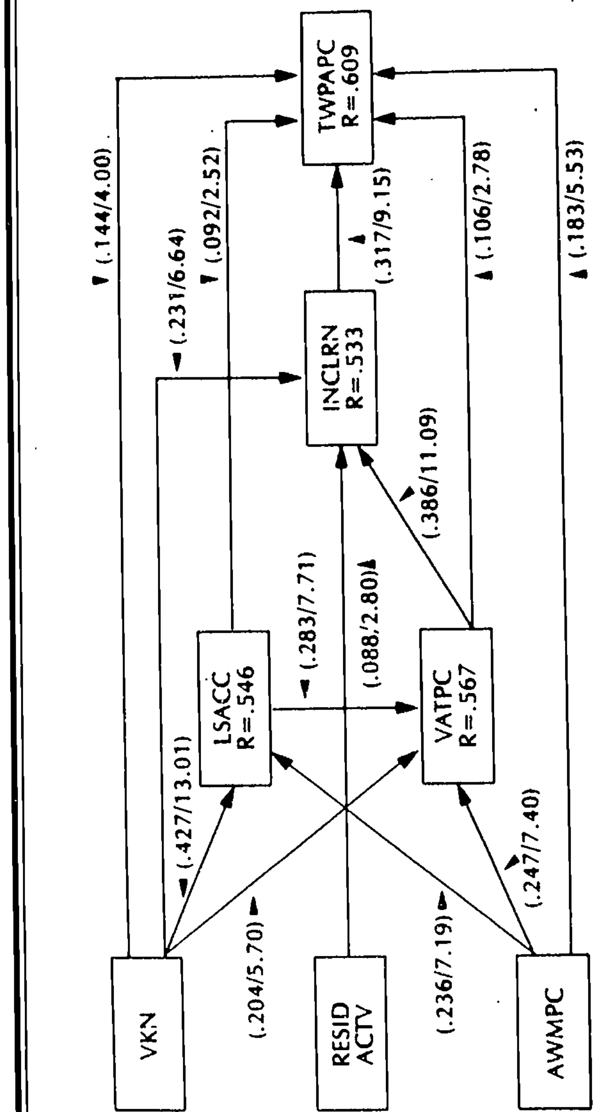

FIGURE 1. Path Model A, depicting relationships among cognitive variables. Numbers in parentheses indicate beta coefficient/z statistic. Variable labels: RESID ACTV = Residual Activation; AWMPC = Alphabet Working Memory; LSACC = Lexical/Semantic Processing Accuracy; VATPC = Verbal Analogy Solution; INCLRN = Incidental Learning; TWPAPC = Trigram-Word Paired Associates. Not shown are correlations among independent variables: r(RESID ACTV, AWMPC) = .097; r(VKN, RESID ACTV) = −.054; r(VKN, AWMPC) = .302. RESID ACTV was reflected in order to maximize the number of positive correlations. All beta coefficients were significant.

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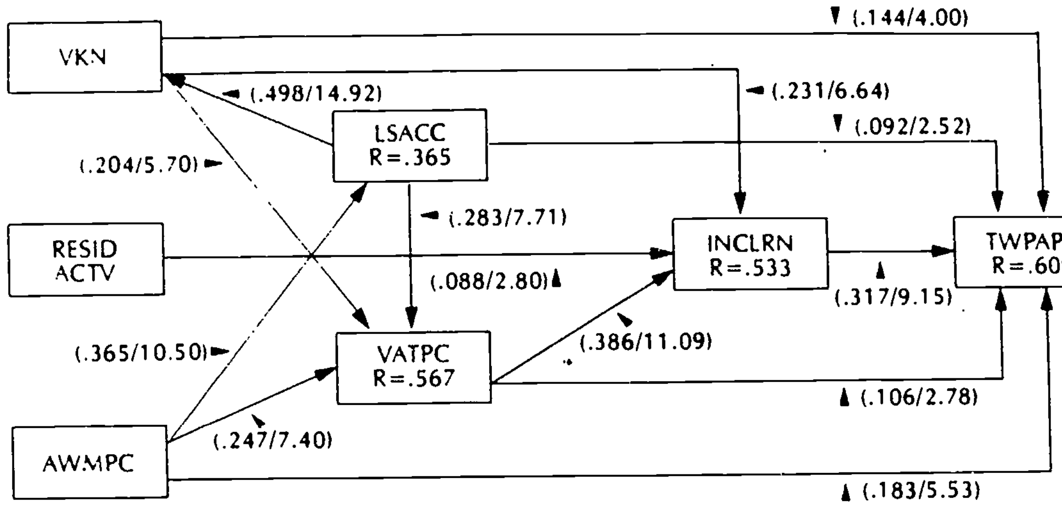

FIGURE 2. Path Model B, depicting relationships among cognitive variables. Numbers in parentheses indicate beta coefficient/z statistic. Not shown is correlation among independent variables: r(RESID ACTV, AWMMPC) = .097.

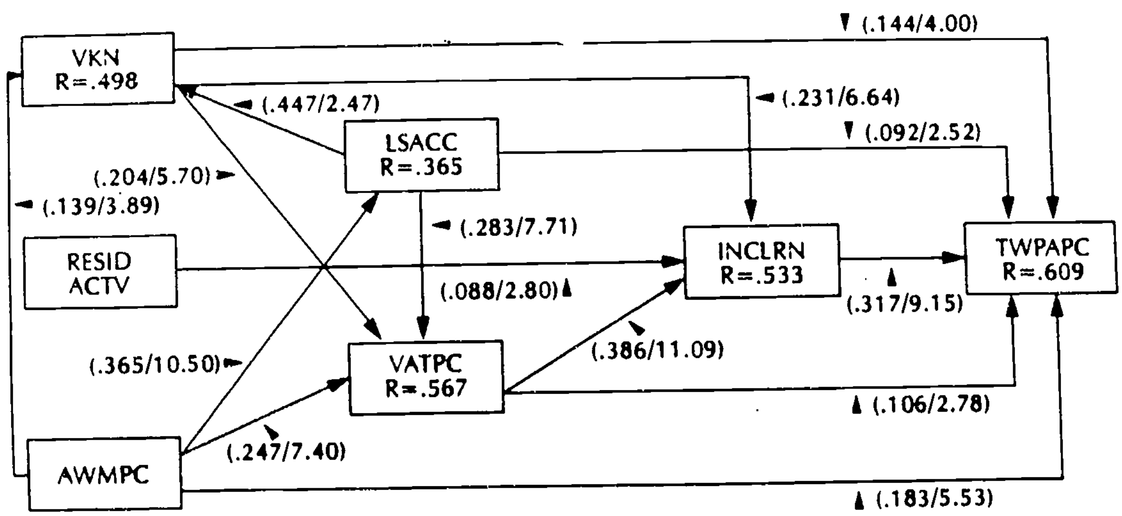

FIGURE 3. Path Model C, depicting relationships among cognitive variables. Numbers in parentheses indicate beta coefficient/z statistic. Not shown is correlation among independent variables: r(RESID ACTV, AWMPC) = .097.

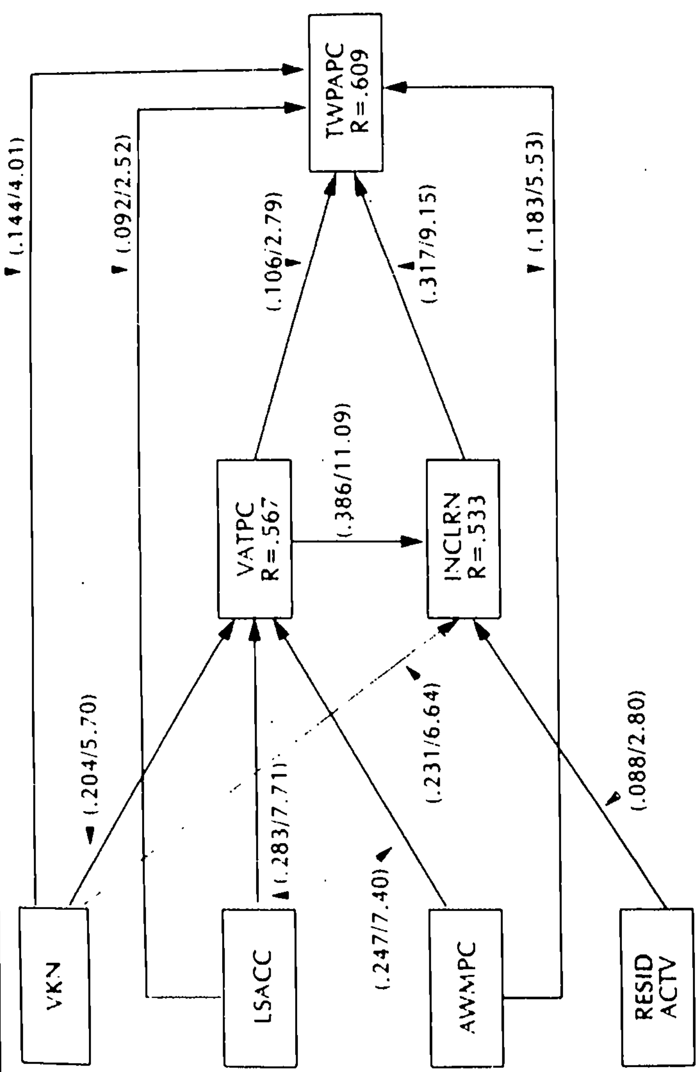

FIGURE 4. Path Model D depicting relationships among cognitive variables. Numbers in parentheses indicate beta coefficient/z statistic. Not shown are correlations among independent variables: r(RESID ACTV, AWMPC) = .097; r(AWMPC, LSACC) = .365; r(LSACC, VKN) = .498; r(RESID ACTV, LSACC) = .010; r(VKN, AWMPC) = .302; r(VKN, RESID ACTV) = −.054.

be accounted for by the knowledge and cognitive ability constructs suggested by the Kyllonen and Christal (1988) framework. The following abilities are suggested as possible determinants of success in acquiring meaningful associations: verbal knowledge, strategic knowledge, working memory, semantic inference as reflected in analogical reasoning, incidental learning proficiency, and lexical/semantic information processing ability reflected in either accuracy or speed.

There were a few unexpected results. First of all, only with the TWPAF8PC (initial eight trials) learning criterion were the Kyllonen et al. (1989) strategy effects replicated. In the Kyllonen et al. study, strategy interacted with verbal knowledge so that students with more knowledge appeared to benefit more from mnemonic instructions than did students with less knowledge, though all subjects benefitted some. In the present study, this effect was obtained only for the first eight trials learning criterion and was stronger for the semantic elaboration strategy set. In the Kyllonen et al. procedure, subjects studied a list of 10 word pairs for a fixed period of time, responded to a type of cued-recall test, and then moved on to a new list. The first eight trials of the present study's procedure were identical in operation.

One interpretation of these findings is that for young adults, students with more verbal knowledge benefit sooner from instructions to use elaboration strategies than students with less verbal knowledge. Eventually students at each point along the verbal knowledge continuum benefit from mnemonic instruction, suggesting that the less-knowledgeable students are learning to learn, that is, learning how to apply the new strategy with practice.

Although interactive imagery and semantic elaboration instructional sets were not distinguishable in terms of interactions with cognitive ability variables, this issue deserves further attention because vividness of imagery and spatial-visualization tests were not included in the predictor set. Interestingly, however, mechanical comprehension skill, which has a visualization component, did not interact significantly with interactive imagery instructions.

A second surprise was that lexical/semantic processing speed was generally less predictive of learning than lexical/semantic processing accuracy. Tests in this category were designed to be relatively easy for high school graduates; errors were probably more often the result of careless mistakes than of knowledge deficits. This finding may suggest that carefulness in processing information might be more important than speed when attempting to learn new associations. However, processing speed (measured here as response time) was predictive of trials-to-criterion; so the importance of processing speed should not yet be discounted.

The most interesting findings of the current study involve the role of incidental learning proficiency and semantic inference (as measured by verbal analogies) in paired-associates learning. The incidental learning tasks used in this study were designed to reflect the ability to recall semantic correlates

after processing word pairs in a deep, semantic manner with no conscious effort to memorize them. Incidental recall proved to be the best predictor of intentional paired-associates learning, with verbal analogies close behind in predictiveness. When incidental recall was removed from the predictor set, verbal analogy solution became the best predictor, followed by working memory. When incidental recall was used as the dependent variable, verbal analogy solution emerged as the best predictor, followed by verbal knowledge. Working memory did not contribute directly to the prediction of incidental learning, suggesting that incidental learning is largely an automatic consequence of having activated semantic relations.

These findings are generally consistent with the theories of Bjorklund (1987), Kyllonen et al. (1989), and Rohwer (1980), but suggest a slight elaboration. Paired-associate learning may have two major processing components, one automatic and one controlled. The data suggest that a substantial part of intentional associative learning occurs automatically as a consequence of the activation of semantic relations in memory. Subjects with more verbal knowledge should be expected to establish new associations more easily because they are more likely to have similar relations already encoded in semantic memory. Working memory capacity does not appear to play a direct role in this type of processing, though there is a possibility that activation capacity as defined by Woltz (1988) is involved, given its significant unique contribution to the prediction of incidental learning in the present study.

The controlled processing component involves the conscious act of constructing meaningful and memorable connections between stimuli. This is similar to the processing that occurs in the verbal analogy solution; that is, semantic elaboration and semantic inference both involve relation construction. In fact, one might suspect that the primary reason incidental learning is better than the verbal analogy solution as a predictor of meaningful associative learning is that the former task shares a cued-recall requirement with the criterion. Working memory capacity, more specifically the variety described as attentional capacity by Woltz (1988), appears to be involved in this type of processing.

Several questions remain to be investigated more fully. Among these are the roles of lexical/semantic processing speed and accuracy in paired-associate learning, the role of mnemonic knowledge and its interaction with verbal knowledge, and the role of self-knowledge concerning one's learning abilities. Although several issues await further investigation, this study shows that success in paired-associates learning can be predicted with fair precision by measures of verbal knowledge and cognitive abilities. Approximately 68% of the systematic variance in simple learning by accretion was explainable by the cognitive variables selected, leaving 32% of the variance as potentially unique to this form of learning. This observation is consistent with the fact

that associative memory emerges as a separate factor in factor analyses o fairly high-level cognitive ability tests (e.g., Thurstone, 1938).

The present study demonstrated that the Kyllonen and Christal (1988 framework is a useful heuristic for studies of individual differences in learning. Its usefulness might prove to be even greater in specifying predictors fo more complex types of learning, e.g., acquisition of computer programming skills, which probably include simple accretive learning as one of severa components. LAMP research is currently concerned with the study of individual differences in complex skill acquisition, and has targeted several skills relevant to the Air Force for investigation.

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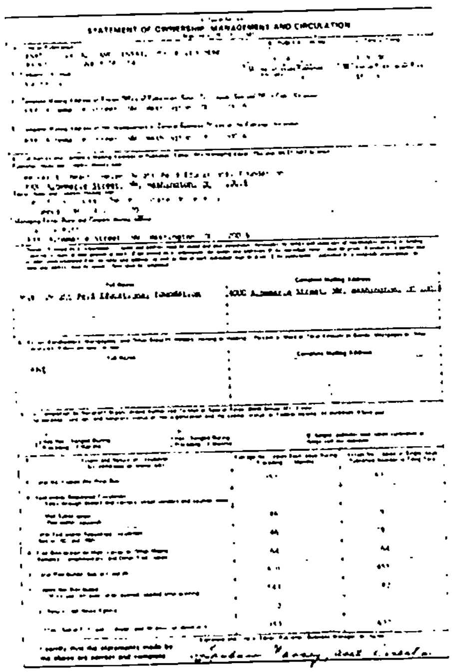
STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION

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